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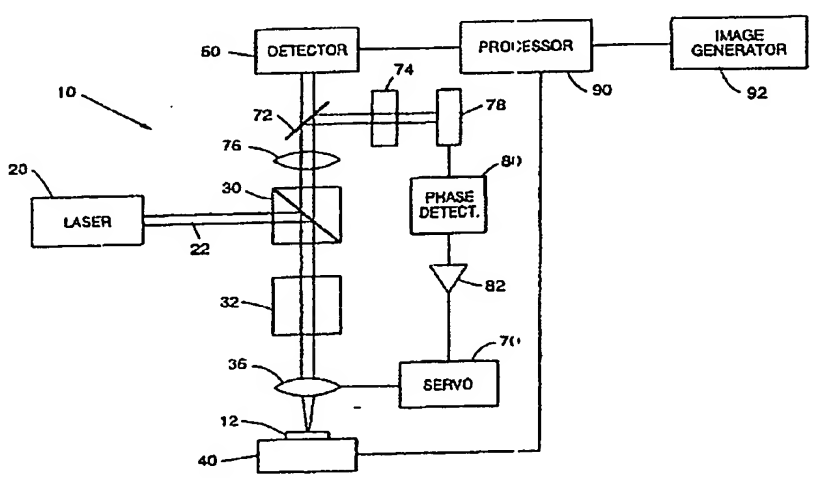

(57) Abstract

An apparatus (10) for generating images of the surface topography of a sample (12) is disclosed. In the apparatus, a probe beam (22) is focused and scanned over the surface of the sample (12). The displacements of the reflected probe beam which are the result of angular deviations in the beam caused by surface features are measured. The displacements are used to generate images of the surface features. The images are derived from displacements either parallel or perpendicular to the direction of the scan. Additional images can be generated using a composite of both displacements.

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APPARATUS FOR GENERATING SURFACE TOPOGRAPHICAL IMAGES

This application is a continuation-in-part of prior copending application Serial No. 07/602,475, filed October 24, 1990.

Technical Field

The subject invention relates to a device for generating surface topographical images. The device can produce images of angstrom size features and is particularly suitable for analyzing semiconductor wafers.

Background of the Invention

In the prior art, a number of systems have been developed to measure variations in the surface topography of various samples. Many of these systems employ optical measurement techniques which have the advantage of being both nondestructive and noncontact approaches. In these devices, a probe beam is scanned over the surface of the sample. Various techniques are used to detect changes in the probe beam due to surface irregularities.

One example of a prior art technique can be found in U.S. Patent No. 4,714,348, issued December 22, 1987 to MaKosch which discloses an interferometric approach. An approach which measures the amount of light which is scattered from a probe beam is described in U.S. Patent No. 4,859,062, issued August 22, 1989 to Thurn et al. In U.S. Patent No. 4,798,469, issued January 17, 1989 to Burke, an apparatus is disclosed which monitors the variation in the diameter of a reflected spot to provide topographical information. The latter approach relies on the same principles as autofocusing techniques.

The subject invention is based on measuring the angular deviations of a specularly reflected probe beam that are induced by surface irregularities. The measurement of angular deviations of a specularly reflected probe beam has been used to evaluate surface topography. (See for example, U.S. Patents No. 3,667,846, issued June 6, 1972 to Nater et al.; No 3,857,737, issued December 31, 1974 to Obenreder; and No. 4,763,006, issued August 9, 1988 to Rau et al.) It is believed that none of the above cited systems could be used to evaluate surface irregularities on the angstrom scale. Moreover, none of these prior art patents disclosed methods for generating high resolution visual images of the surface of the sample.

Accordingly, it is an object of the subject invention to provide an apparatus for measuring the surface topography of a sample.

It is another object of the subject invention to provide an apparatus for generating images of the surface topography of a sample.

It is a further object of the subject invention to provide an apparatus which can measure surface irregularities on the angstrom scale.

It is still another object of the subject invention to provide an apparatus which can generate images based on the angular deviation of a probe beam.

It is still a further object of the subject invention to provide an apparatus which can generate images based on the angular deviation of a probe beam which occurs in the direction of the scan of the probe beam.

It is still another object of the subject invention to provide an apparatus which can generate images based on the angular deviation of a probe beam

which occurs perpendicular to the direction of the scan of the probe beam.

It is still a further object of the subject invention to provide an apparatus which can generate images based on various composites of the angular deviation of a probe beam which occur both parallel and perpendicular to the direction of the scan of the probe beam.

It is still another object of the subject invention to provide an apparatus which can generate an image which displays the absolute height of surface features on the sample.

Summary of the Invention

In accordance with these and many other objects the subject invention includes laser for generating a collimated probe beam. A high numerical aperture lens is used to focus the probe beam onto the surface of the sample with a spot size of about one micron in diameter. The reflected probe beam is directed to a photodetector which can monitor changes in position of the beam that are result of angular deviations produced by surface features of the sample.

A high precision stage is provided to scan the sample with respect to the probe beam. Surface features will induce angular deviations of the beam both parallel and perpendicular to the direction of the scan. The angular deviations are converted to lateral displacements when the reflected probe beam passes back up through the lens. These lateral deviations are measured by the photodetector.

Images of the surface are created using displacement measurements which are either parallel or perpendicular to the direction of the scan. Images can also be created using various combinations of both orthogonal displacements. As discussed in

detail below, different combinations can be used to enhance different kind of topological features.

An image of the absolute height of surface features can also be generated by integrating the angular deviation measurements with respect to incremental positions of the scanned probe beam.

Further objects and advantages of the subject invention will become apparent from the following detailed description, taken in conjunction with the drawings in which:

Brief Description of the Drawings

Figure 1 is a schematic diagram of an apparatus constructed in accordance with the subject invention.

Figure 2 is a bottom plan view of a quad cell photodetector.

Figures 3a through 3d illustrate the interaction between the probe beam and a surface feature of the sample.

Figure 4 is a perspective view of a surface feature which runs along one of the scan directions.

Figures 5a through 5c are simplified illustrations of the images which can be generated with the subject system.

Figures 6 through 10 are photographs of various images taken of the surface of a sample highlighting one particular surface feature.

Figure 6 is an image which is generated with the subject system using angular deviation measurements parallel to the direction of the scan.

Figure 7 is an image which is generated with the subject system using angular deviation measurements perpendicular to the direction of the scan.

Figure 8 is an image which is generated with the subject system wherein angular deviation measurements

both parallel and perpendicular to the direction of the scan are combined.

Figure 9 is an image which is generated with the subject system wherein angular deviation measurements both parallel and perpendicular to the direction of the scan are combined in a different manner.

Figure 10 is an image which is generated with the subject system wherein angular deviation measurements both parallel and perpendicular to the direction of the scan are combined in the same manner as in Figure 9 and then inverted.

Figure 11 is a line scan which is generated with the subject system using angular deviation measurements to illustrate absolute height variations.

Figure 12 is a diagram illustrating an approach for generating a two dimensional image which displays absolute height information.

<u>Detailed Description of the Preferred Embodiment</u>

Referring to Figure 1, there is illustrated an apparatus 10 for detecting topological features on the surface of a sample 12 and generating images of those features. The apparatus includes a laser 20 for generating a probe beam 22. In the preferred embodiment, laser 20 is a linearly polarized HeNe laser generating an output beam 22 of 633 nm having a 5 mW power.

The probe beam 22 is directed downwardly by a polarizing beam splitter 30 through a quarter wave plate 32. The beam then passes through lens 36 and onto the surface of the sample 12 with 3 mW of incident power.

In accordance with the subject invention, lens 36 is a powerful microscope objective having a high

numerical aperture (NA). The NA of the lens should be at least 0.5 and is preferably on the order of 0.95. This diffraction limited optical arrangement is arranged to produce spot sizes on the sample having a diameter on the order of one micron. In the preferred embodiment, the spot size is set to 0.8 microns. The lens is spaced from the surface of the sample an amount substantially equal to its focal length. This position is maintained using an autofocus mechanism discussed in greater detail below.

A stage 40 is provided to support the sample 12 and for scanning the sample with respect to the probe beam in two orthogonal directions. In the preferred embodiment, a dc servo stage is used, manufactured by Kensington Labs. The stage utilizes an optically encoded feedback control system so movements in either the X or Y direction can be controlled to within 500 angstroms. This stage also provides for rotation of the sample.

The reflected probe beam will pass back up through lens 36 and quarter wave plate 32. The two passes through the quarter waveplate 32 function to rotate the polarization of the beam a full 90 degrees so that when the beam reaches splitter 30 it will pass therethrough to fall on photodetector 50. Photodetector 50 is of the type which can detect displacements of the probe beam. A photodetector having an two dimensional array of detecting elements could be used. In the illustrated embodiment, a quad cell detector is used and the optics are arranged such that the probe beam will underfill the detector.

The use and operation of quad cell detectors is well known in the art. The surface of the quad cell detector is illustrated in Figure 2. Briefly, each of the four quadrants (52, 53, 54, 55) generates

separate voltage levels proportional to the power of the light falling on that segment. When the beam 22 is centered, each of the four quadrants will generate the same voltage. When the position of the beam moves from the center (shown schematically as 22a), the voltage levels will vary and position information can be determined.

For example, to determine the displacement of the beam in the X direction, the sum of the output voltage generated by the two quadrants (52, 55) on the left side of Figure 2 would be subtracted from the sum of the output voltage generated by the two quadrants (53, 54) on the right side of the Figure. The displacement in the Y direction would be determined in a similar manner comparing the outputs from the top two quadrants (52, 53) with the bottom two quadrants (54, 55). In the preferred embodiment, the difference voltages are divided by the sum of the voltages of all the quadrants to normalize the result.

Figures 3a through 3d illustrate how angular deviations of the beam due to changes in surface topography are converted into lateral displacements of the beam at the detector. As shown in Figure 3a, when the beam is reflected off a flat surface, it will pass back through the center of the lens 36 and strike the detector at the center. As the probe beam is scanned across a hillock 60 (in the X direction), the beam will deviate angularly backwards (negative X), parallel to the direction of the scan as shown in Figure 3b. Since the surface of the sample is substantially in the focal plane of the lens, the reflected beam will be redirected by the lens along a path parallel to but laterally displaced from the incoming probe beam. The amount of negative displacement is proportional to the local slope of

the surface feature 60. By monitoring the extent of this displacement, the slope of the surface feature can be determined.

Figure 3c illustrates that at the crest of the hillock, where the slope is zero, there will be no displacement and the beam will be once again centered on the detector. As the scan continues, the angle of the beam will again deviate in a plane parallel to the direction of the scan but in a forward sense. As can be seen, a positive lateral displacement will occur proportional to the slope of the feature but have an opposite sign (positive X). Using this convention, a feature which initially produces a negative displacement followed by a positive displacement will be feature which is raised from the surface. In contrast, a depression or hole will characteristically produce an initial displacement of the probe beam in the positive direction and then a displacement in the negative direction (with an intermediate, zero displacement).

It should be noted that the assignee of the subject invention has previously developed an optical system for measuring the angular displacements of the sample surface induced by and in phase with an intensity modulated pump laser. This system is described in U.S. Patent Nos. 45,521,118 and 4,522,510, incorporated herein by reference. In the latter system, the intensity modulated pump laser created periodic angular surface changes at the surface of the sample. The extent of those periodic angular surface changes could be analyzed to evaluate surface and subsurface features of the sample. The latter system was not operated in a manner to measure existing topographical features.

Figure 3 illustrates the angular deviation of the probe in only the X axis, parallel to the

direction of the scan. If the feature 60 were symmetrical about the vertical direction, the magnitude of the displacements in the Y axis would be the same. However, many features are asymmetric. More importantly, in semiconductor samples, some features tend to have symmetries that lie along one of the two axes. Such a feature is shown in Figure 4 wherein a trough is shown to run along the Y-axis. As noted above, in a scan of a depression along the X axis, the beam will first be displaced in a direction forward of the scan direction (as shown in the Figure) and thereafter will return to zero and then be displaced negatively. However, the slope of the feature in the Y direction remains constant. Therefore, any scan in the Y direction will not produce any angular deviation of the probe beam in that direction and therefore will be reflected back through the lens 36 with no displacement in the Y direction as shown in Figure 4. For this reason, it is desirable to be able to generate images of a sample in both the X and Y directions and images that are based on a combination of both signals so that all features can be imaged.

Having described the basics of the system, some additional details of the subject apparatus 10 will now be discussed. For example, as noted above, the lens 36 is maintained a distance from the surface of the sample an amount substantially equal to the focal length of the lens. In the case of the preferred 0.95 NA lens, this distance is about 300 microns. This distance is maintained to less than one tenth of a micron through the use of an autofocus mechanism.

The autofocus mechanism includes a servo motor 70 for varying the vertical position of the lens 36. The servo is driven by an analog detection loop which determines if the lens 36 is properly focusing the

probe beam. As seen in Figure 1, a partially reflective mirror 72 picks off a small portion of the reflected probe beam and directs it to a chopper wheel 74. A lens 76 is positioned in the path of the reflected probe beam such that the chopper wheel 74 is in the focal plane of the lens. The light passing the chopper wheel 74 is imaged on a split cell photodetector 78. If the lens 36 is out of focus, there will be a phase difference in the light striking the two sides of the split cell 78 which is detected by a phase detector 80. The phase difference is used as an input to an amplifier 82 which in turn drives the servo. This approach to autofocusing is known as automated Foucault testing. It should be noted that the deviations in the sample which effect the movement of lens 36 are several orders of magnitude greater than the surface features which are to be imaged.

As noted above, the output from quad cell detector can be used to generate images of the surface topography of the sample. This output can be combined in various ways to achieve different results. The combination process can be performed in a processor 90 and then sent to an image generation apparatus 92. The imager 92 can be a video monitor or video hard copy printer.

In the preferred method of the subject invention, the probe beam is scanned across the sample using the stage along a plurality of parallel lines. For convenience, the direction of the scan can be referred to as the X direction.

Typically, the scan will move across a first line taking measurements at discrete intervals. The spacing between the intervals can be adjusted from 500 angstroms to 16,000 angstroms. To maintain the desired resolution, the increments utilized should be

2000 angstroms or less. At the end of the scan line, the sample is shifted over one increment in a direction perpendicular to the scan line and a new scan is started. If the smallest measurement increment is chosen, a magnification of 13,600 times can be achieved. In practice, features with a height in the range of a few crystallographic dimensions have been clearly observed. For example, a slip line in a silicon wafer approximately 8 angstroms in height, which created a slope of 0.015 degrees over a linear distance of 3 microns was observed.

Scans can be executed over regions of different sizes. The preferred embodiment is programmed to generate images ranging from 12 square microns to 800 square microns.

As noted above, the displacement of the probe beam along the surface of the detector is proportional to the slope of the surface feature on the sample. This relationship holds true for slopes which do not exceed about 16 degrees. For steeper slopes, the relationship loses its linearity and some additional calibration may be necessary. In any case, any scan should begin on a flat surface to insure that the data is properly interpreted.

Figures 5a though 5c are simplified illustrations of basic scans of three different features which are obtained using signals either parallel or perpendicular to the scan (X) direction. In these figures, the imager is programmed such that a zero signal or no displacement will be represented by the middle of a grey scale. As the displacement (and slope of the feature) increases in a positive direction, the brightness of the image is increased with maximum positive displacement being depicted as white. Conversely, maximum negative displacement is depicted as black.

The above described convention is useful for standard black and white video images. However, various other composition variables, such as color, could be used to illustrate variations in surface topography.

Figure 5a illustrates the images which would be generated of a hillock using this convention. As noted above in the case of a hillock, the signals parallel to the direction of the scan (X direction) will first have a large negative value (dark) move to neutral and then increase to a maximum positive value. This convention is not unlike having a light source illuminate the feature from the top of the figure. The displacements of the beam which are perpendicular to the scan direction (Y direction) will generate an image where the illumination source appears to be from the left. The illumination analogy applies for each of the Figures and is useful in interpreting the images.

Figure 5b shows the images generated from the parallel (X) and perpendicular (Y) signals when scanning a pit or depression in the sample surface. It should be noted that the shading patterns are reversed from Figure 5a. Figure 5c illustrates the images that would be generated from a notch or depression at the edge of the sample.

Figures 6 through 11 are photographs of actual images taken with the device of the subject invention. The surface feature imaged consists of an engraved letter "C" enclosed within an engraved octagon design. The octagon design is 100 microns across and the engravings have a depth of 0.1 microns (1000 angstroms). The scanning increment was set to 4000 angstroms. As each of these photographs are reviewed, it will be observed that various features

are enhanced or suppressed depending upon the signals that are processed. The images

Figure 6 is an image of the feature using signals generated from displacements parallel to the direction of the scan (X direction). As noted above, this convention tends to produce images where a light source appears to illuminate the feature from the top of the image. It should also be noted that the left and right hand sides of the octagon and the left hand side of the letter "C" are suppressed. This result occurs because the slope of these features is constant along the axis parallel to the scan.

Figure 7 is an image based on beam displacement in a direction perpendicular to the scan (Y direction). In this image, the top and bottom of both the octagon and letter "C" are suppressed since these features do not change slope in the Y direction.

Since many surface features in real samples occur along one of the two perpendicular directions, additional images are desirable. Figure 8 illustrates one of those images. In Figure 8, the displacements in both the X and Y direction are summed and then plotted. This approach has the effect of shifting the source of illumination 45 degrees so that all of the X and Y features are enhanced. It should be noted that some of the angled portions of the feature are less prominent.

Various linear combinations of the X and Y displacements signals can be used to make the illumination appear to come from any azimuthal angle. One approach would be to combine the signals in accordance with equation (1) below.

$$\text{(1)} \quad \text{Image value} = X \cos\theta + Y \sin\theta$$

where θ is the desired azimuthal angle. Note that when θ is zero degrees, the image generated will be like that shown in Figure 6, whereas when θ is 90 degrees, the image generated will be like Figure 7.

Still another imaging approach is illustrated in Figure 9. In this approach the value for the contrast signal (R) at each point in the image is arrived at using the following formula:

$$(2) \qquad R = \sqrt{X^2 + Y^2}$$

As can be appreciated, this formula eliminates the sign (+ or -) from the data and produces an absolute value of the displacement or slope of the feature. With respect to the image, the steeper the feature, the more it will be illuminated, regardless of whether it is a down slope or an up slope. This type of image is desirable when one wants to obtain an overall picture of the variations in surface topography without regard to the type of feature being imaged.

The data points used to generate the image in Figure 10 are obtained by first calculating the value of R as set forth above in equation 2. Thereafter, this value is simply inverted so that the highest values are given the darkest color and the lowest values the brightest color. Similar to Figure 9, this image also gives an overall picture of variations in surface topography. However, this image has the added advantage in that it is more consistent with human observation in standard lighting conditions wherein flat areas are brightly illuminated and slopes tend to be shaded.

The subject invention can be further used to determine the absolute value of the height of a feature. As noted above, the displacements in the

beam can be converted directly into the slope of the surface. Height information can be determined by integrating this slope information with respect to the increments between data points. As noted above, in the preferred embodiment, the stage is typically moved in increments that range from 500 angstroms to 2000 angstroms. Using these small increments for the integration, extremely accurate height information can be generated.

Figure 11 is a graph which gives height information with respect to the position of the beam on the sample along a single scan line. An image similar to Figures 6 through 10 could be generated from multiple parallel line scans.

In order to generate a two dimensional image which displays absolute vertical height information, both X and Y angular deviation signals are required. This requirement can best be appreciated by referring to Figure 12. Figure 12 is a schematic illustration of a rectangular scan area on the surface of the sample. Data point 93 is located at point X_1, Y_1, within the scanned region.

In order to determine the height of location 93 with respect to starting point 94 (X_0, Y_0) the slope signals along both the X and Y directions must be considered since surface changes in both directions contribute to the height Z of data point 93. Accordingly, to arrive at a height Z, the first step is to integrate the individual displacement (slope) measurements along the X axis from point 94 to point 95 (X_1, Y_0) as shown in equation (3).

$$(3) \qquad \int_{X_0}^{X_1} \text{X displacement} \,\Big|_{Y = Y_0}$$

The next step is to integrate the slope measurements along the Y axis, from point 95 to point 93 as shown in equation (4).

$$(4) \qquad \int_{Y_0}^{Y_1} \text{Y displacement} \,\Big|_{X = X_1}$$

The results from equations (3) and (4) are then summed to give the height of point 93 with respect to the origin at point 94.

In the preferred embodiment, the value can be more accurately determined by performing the complimentary calculations along a path from the starting point 94, to point 96 (X_0, Y_1) and then to point 93 according to formulas (5) and (6) below.

$$(5) \qquad \int_{Y_0}^{Y_1} \text{Y displacement} \,\Big|_{X = X_0}$$

$$(6) \qquad \int_{X_0}^{X_1} \text{X displacement} \,\Big|_{Y = Y_1}$$

Theoretically, the sum of equations (5) and (6) will equal the sum of equations (3) and (4). In practice, all four of the equations cane be summed and the result divided by two so that any measurement errors are averaged and minimized thereby achieving a more accurate result for the value of Z at point 93.

The subject topographical imaging system has been incorporated into a thermal wave imaging system marketed by Therma-Wave, Inc., the assignee of the subject invention. When used together, the thermal wave and topographical images provide a powerful tool for the analysis of semiconductor IC devices. More particularly, one can compare the images generated of an area of a wafer to determine whether the observable artifacts are caused by either surface and subsurface anomalies.

In summary, there has been provided an apparatus for generating images of the surface topography of a sample. In the apparatus, a probe beam is focused and scanned over the surface of the sample. The displacements of the reflected probe beam which are the result of angular deviations in the beam caused by surface features are measured. The displacements are used to generate images of the surface features. The images are derived from displacements either parallel or perpendicular to the direction of the scan.. Additional images can be generated using a composite of both displacements.

While the subject invention has been described with reference to a preferred embodiment, various changes and modifications could be made therein, by one skilled in the art, without varying from the scope and spirit of the subject invention as defined by the appended claims.

CLAIMS

1. An apparatus for generating images of the surface topography of a sample comprising:

means for generating a probe beam;

means for directing said probe beam onto the surface of the sample;

means for scanning the probe beam relative to the sample;

means for measuring the angular deviations of the specularly reflected probe beam with respect to its position on the sample surface, said angular deviations being induced by variations in the surface topography of the sample; and

means for generating a visual image of the surface topography of the sample based on the measured angular deviations.

2. An apparatus as recited in claim 1 wherein said means for directing said probe beam onto the surface of the sample is a lens having a numerical aperture of at least 0.5.

3. An apparatus as recited in claim 1 wherein said means for directing said probe beam onto the surface of the sample is a lens having a numerical aperture of at least 0.95.

4. An apparatus as recited in claim 1 wherein said means for measuring the angular deviations of the probe beam is defined by a quad cell photodetector.

5. An apparatus as recited in claim 1 wherein said scanning means scans the probe beam relative to

the surface of the sample over multiple parallel scan lines.

6. An apparatus as recited in claim 5 wherein said visual image is generated using angular deviation measurements which occur parallel to the direction of the scan.

7. An apparatus as recited in claim 5 wherein said visual image is generated using angular deviation measurements which occur perpendicular to the direction of the scan.

8. An apparatus as recited in claim 5 wherein said visual image is generated by using the sum of the angular deviation measurements which occur both parallel and perpendicular to the direction of the scan.

9. An apparatus as recited in claim 5 wherein said visual image is generated by using the square root of the sum of the squares of the angular deviation measurements which occur both parallel and perpendicular to the direction of the scan.

10. An apparatus as recited in claim 5 wherein said visual image is generated by calculating the square root of the sum of the squares of the angular deviation measurements which occur both parallel and perpendicular to the direction of the scan and inverting the result.

11. An apparatus as recited in claim 5 wherein a visual image of the vertical height variations of the sample is generated by using data generated by integrating the angular deviation measurements with

respect to the incremental positions of the scanned probe beam.

12. An apparatus as recited in claim 1 wherein the extent of the angular deviation measurements are depicted in the image by varying a parameter of the image with respect to the magnitude of the measurement.

13. An apparatus is recited in claim 12 wherein the brightness of the image is varied with respect to the magnitude of the angular deviation measurements.

14. An apparatus as recited in claim 13 wherein a zero angular deviation measurement is depicted by neutral brightness and positive and negative angular deviation measurements are depicted by either brighter or darker images.

15. An apparatus as recited in claim 1 wherein said means for generating a probe beam is a laser.

16. A method for generating images of the surface topography of a sample comprising the steps of:

scanning a probe beam relative to the surface of a sample;

measuring the angular deviations of the specularly reflected probe beam with respect to its position on the sample surface, said angular deviations being induced by variations in the surface topography of the sample ; and

generating a visual image of the surface topography of the sample based on the measured angular deviations.

17. A method as recited in claim 16 wherein the probe beam is scanned relative to the surface of the sample over multiple parallel scan lines.

18. A method as recited in claim 17 wherein said visual image is generated using angular deviation measurements which occur parallel to the direction of the scan.

19. A method as recited in claim 17 wherein said visual image is generated using angular deviation measurements which occur perpendicular to the direction of the scan.

20. A method as recited in claim 17 wherein said visual image is generated by using the sum of the angular deviation measurements which occur both parallel and perpendicular to the direction of the scan.

21. A method as recited in claim 17 wherein said visual image is generated by using the square

root of the sum of the squares of the angular deviation measurements which occur both parallel and perpendicular to the direction of the scan.

22. A method as recited in claim 17 wherein said visual image is generated by calculating the square root of the sum of the squares of the angular deviation measurements which occur both parallel and perpendicular to the direction of the scan and inverting the result.

23. A method as recited in claim 17 wherein a visual image of the vertical height variations of the sample is generated by using data generated by integrating the angular deviation measurements with respect to the incremental positions of the scanned probe beam.

24. A method as recited in claim 16 wherein the extent of the angular deviation measurements are depicted in the image by varying a parameter of the image with respect to the magnitude of the measurement.

25. A method is recited in claim 24 wherein the brightness of the image is varied with respect to the magnitude of the angular deviation measurements.

26. A method as recited in claim 25 wherein a zero angular deviation measurement is depicted by neutral brightness and positive and negative angular deviation measurements are depicted by either brighter or darker images.

27. An apparatus for determining the height at a point on the surface of a sample comprising:

means for generating a probe beam;

means for directing said probe beam onto the surface of the sample;

means for scanning the probe beam relative to the sample along a plurality of parallel scan lines;

means for measuring the angular deviations of the specularly reflected probe beam that occur both parallel and perpendicular to the direction of the scan, said angular deviations being induced by variations in the surface topography of the sample; and

means for calculating the height at a point on the surface of the sample based on the measured angular deviations.

28. An apparatus as recited in claim 27 wherein said calculation means functions to integrate the angular deviation measurements.

29. A method for determining the height of a point on the surface of a sample comprising the steps of:

scanning a probe beam relative to the surface of a sample along a plurality of parallel scan lines;

measuring the angular deviations of the specularly reflected probe beam that occur both parallel and perpendicular to the direction of the scan, said angular deviations being induced by variations in the surface topography of the sample; and

calculating the height at a point on the surface of the sample based on the measured angular deviations.

30. A method as recited in claim 29 wherein said calculation step is performed by integrating the angular deviation measurements.

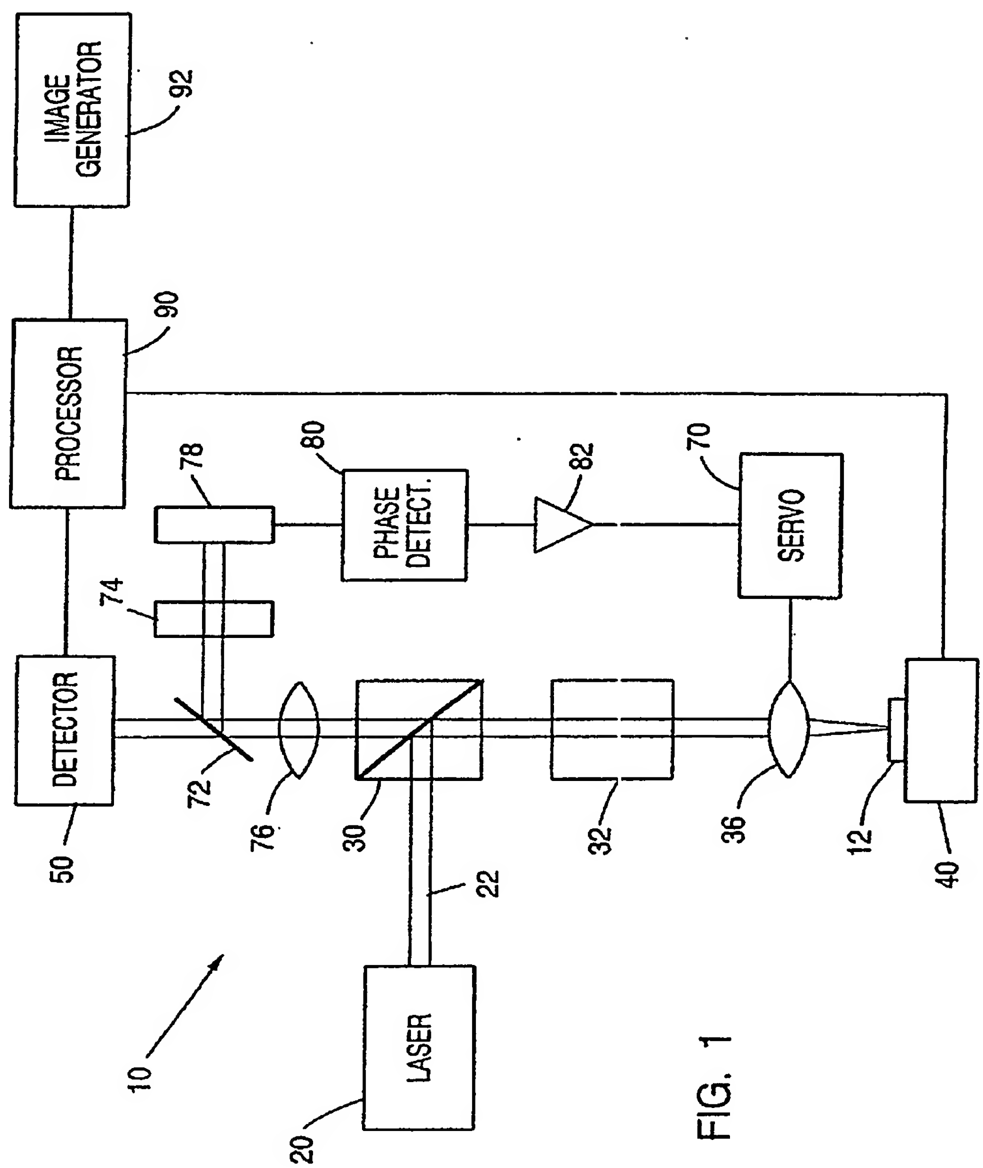


IMAGE GENERATOR
92
PROCESSOR
90
78
80
PHASE DETECT.
82
70
SERVO
74
DETECTOR
72
76
30
32
36
12
40
50
22
10
LASER
20

FIG. 1

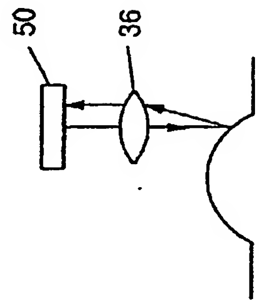


FIG. 3D

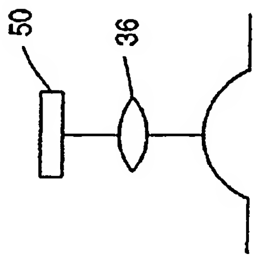


FIG. 3C

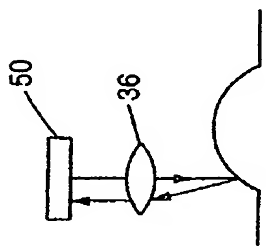


FIG. 3B

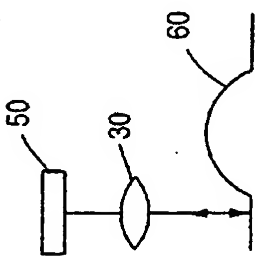


FIG. 3A

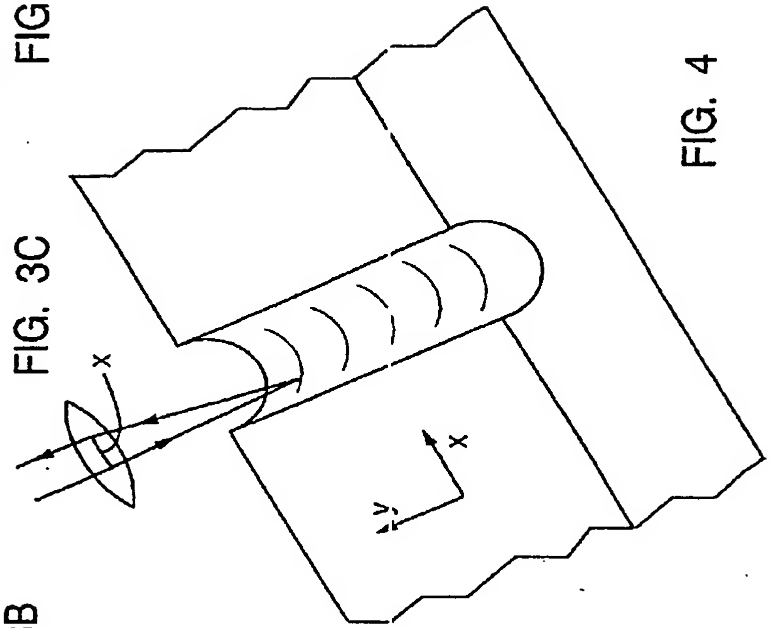


FIG. 4

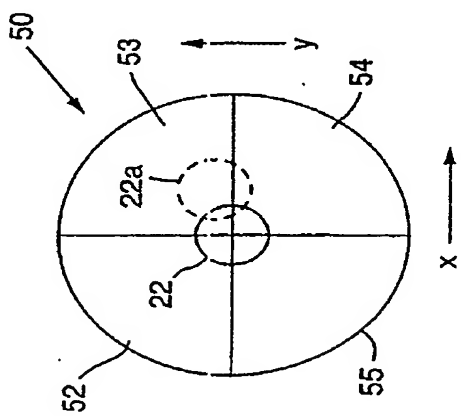


FIG. 2

SUBSTITUTE SHEET

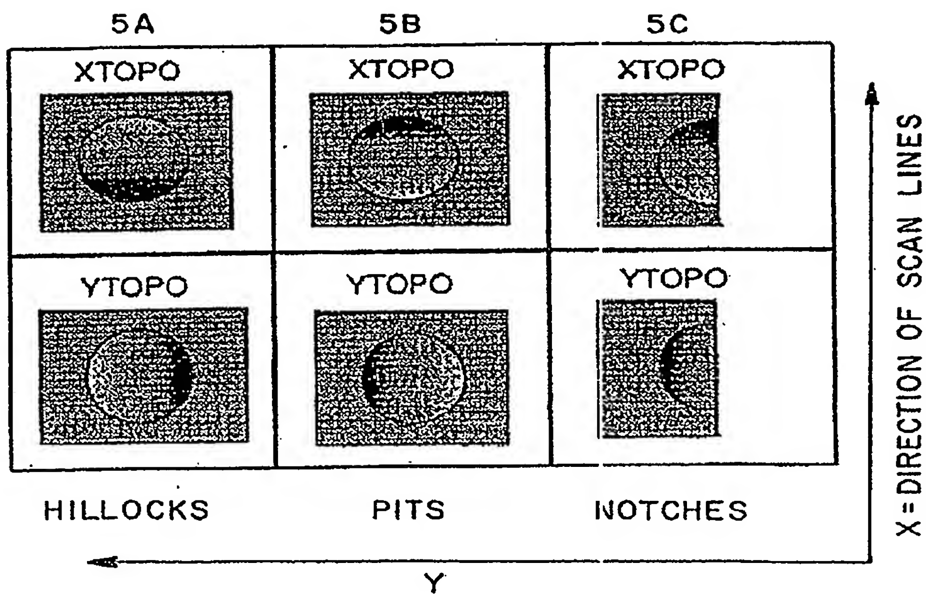
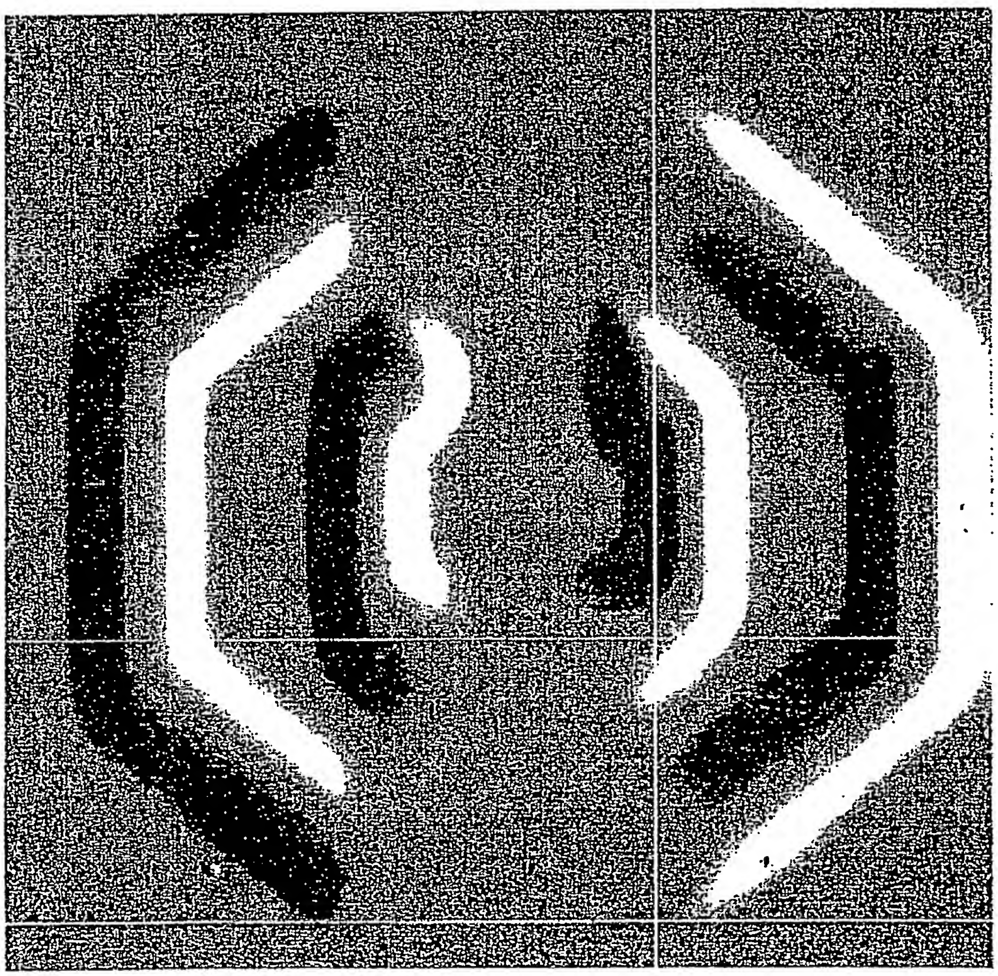

5A
5B
5C
XTOPO
XTOPO
XTOPO
YTOPO
YTOPO
YTOPO
HILLOCKS
PITS
NOTCHES
Y
X = DIRECTION OF SCAN LINES

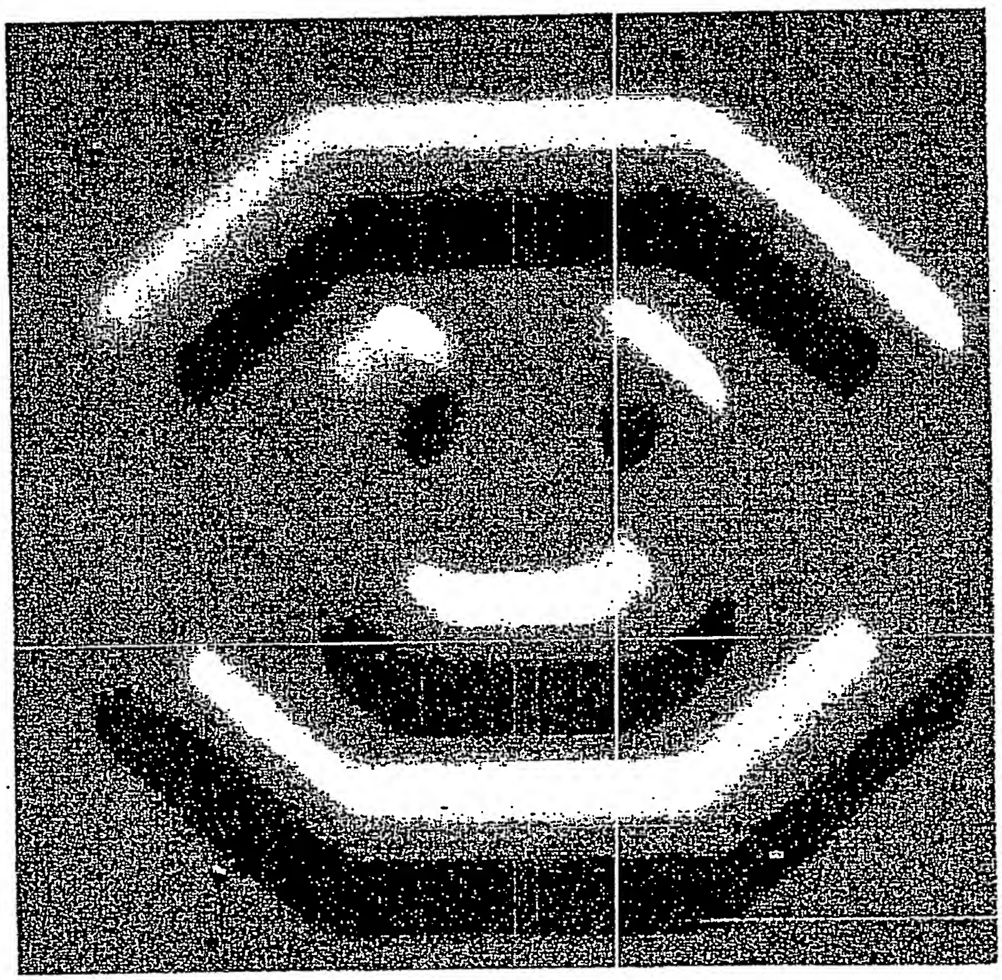
FIG. 5

FIG. 6



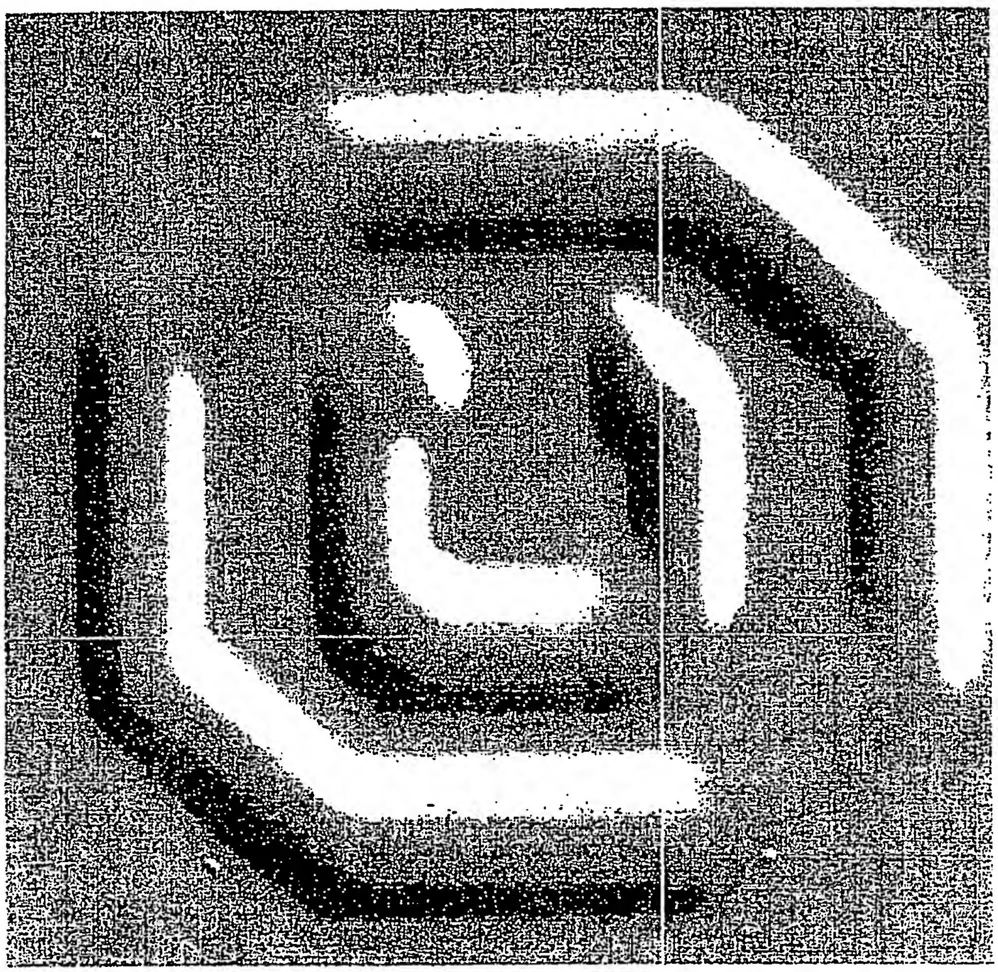
SUBSTITUTE SHEET

FIG. 7



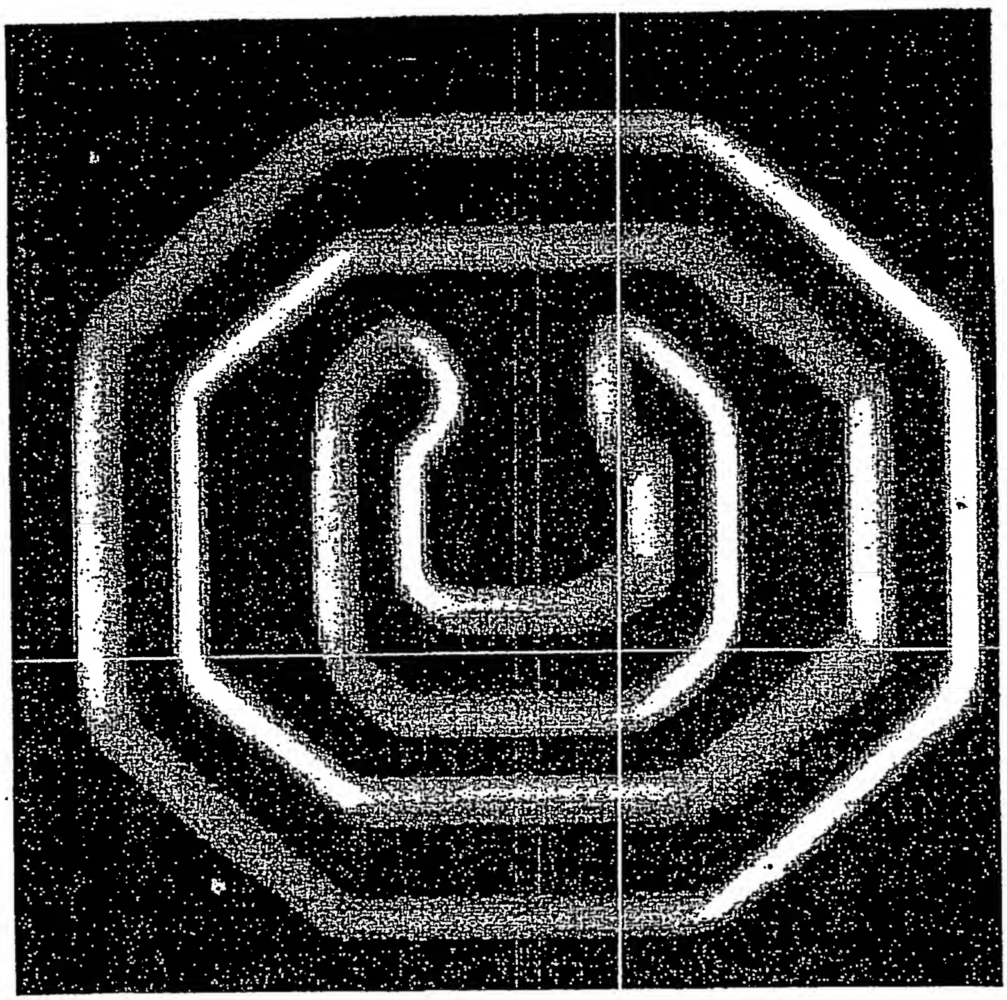
SUBSTITUTE SHEET

FIG. 8



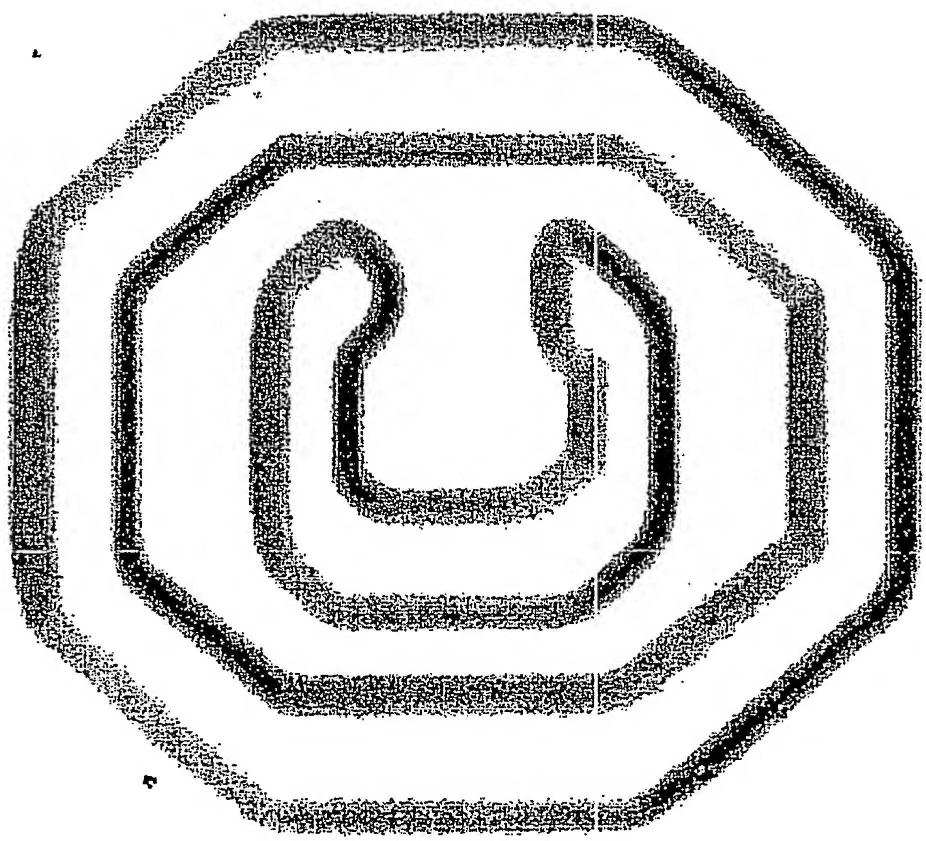
SUBSTITUTE SHEET

FIG. 9



SUBSTITUTE SHEET

FIG. 10



SUBSTITUTE SHEET

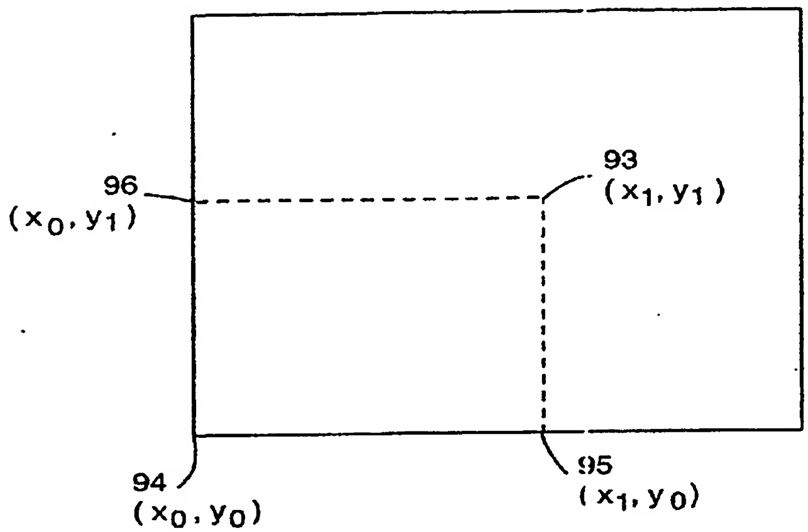
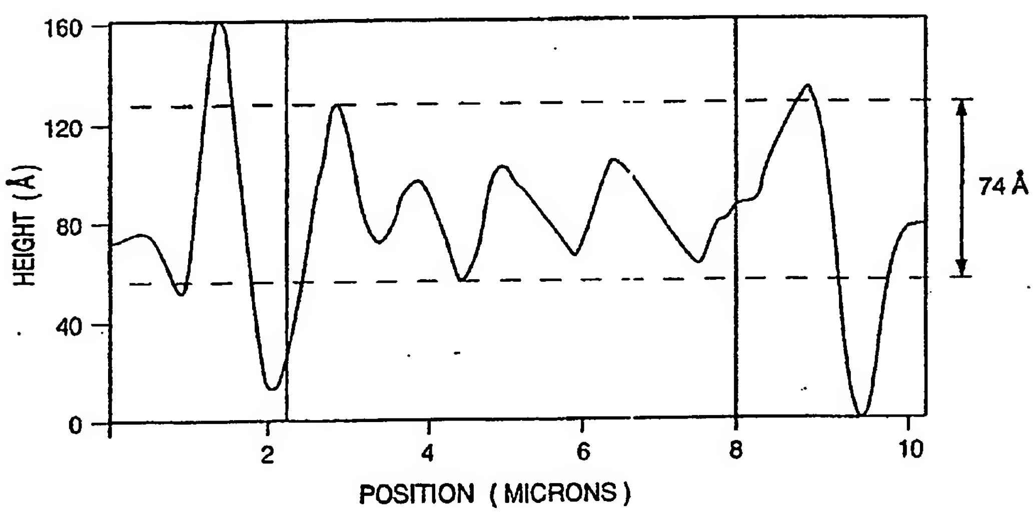


FIG. 12



SUBSTITUTE SHEET

FIG. 11

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/07995

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5) G01B 11/24
U.S.CL 356/376

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S. Cl.	356/371,376

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X Y	IBM Technical Disclosure Bulletin, Vol. 13, no. 3 August 1971, R.W. Harrison, "Laser Scanning Surface Profilometer", pages 789-790. (Note lines 7-11 and 17-21).	1,12,15-16, 23-24 1-30
X Y	US,A 3,885,875 ROSENFELD et al. 27 May 1975 (27.05.75) (Note column 4, lines 56-58 and column 6, lines 63-67).	1,5-7,11-12, 15-19,23-24, 27-30 1-30
X Y	US,A 3,975,102 ROSENFELD et al. 17 August 1976 (17.08.76) (Note Figure 8)	1,5-8,11-12 15-20,23-24 27-30 1-30
Y	US,A 4,332,477 SATO 1 June 1982 (01.06.82) (Note Figure 2)	1-30
Y	US,A 4,427,295 NISHIYAMA 24 January 1984 (10.24.84) (Note Figure 1)	1-30
Y	US,A 4,289,400 KUBOTA et al 15 September 1981 (15.09.81) (Note column 5, lines 52-55)	9-10,21-22

* Special categories of cited documents: [10]
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report [2]
31 January 1992 (31.01.92)	
International Searching Authority	Signature of Authorized Officer
ISA/US	NGOC-HO INTERNATIONAL DIVISION R.A. Rosenberger Ngoc-Ho Nguyen

Form PCT/ISA/210 (second sheet) (Rev.11-87)